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Evaluating the Impact of Ocean Eddies in the Global Marine Carbon Cycle

(w17_OceanEddies)

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Introduction

The ocean plays a crucial role in the Earth's carbon cycle due to its ability to exchange carbon dioxide (CO_2) with the atmosphere, and subsequently store it for long periods of time. Part of this sequestration is due to a mechanism known as the Biological Pump, a process where phytoplankton and autotrophic bacteria convert dissolved CO_2 to organic matter via photosynthesis, much of which ends up sinking and can remain in the deep ocean for hundreds or thousands of years. If the strength of the Biological Pump changes due the human-induced increase in atmospheric CO_2, it will affect the rate of global warming. Earth System Models (ESMs) are now including ocean biogeochemical processes in order to quantify changes in the global carbon cycle under climate change scenarios by embedding a model that represents ocean chemistry and the dynamics of marine ecosystems within an ocean circulation framework. Due to the increased computational cost of including marine biogeochemistry (BGC), they are typically run with relatively low complexity and coarse horizontal grid resolution. Our project utilizes Institutional Computing power to undertake an ESM simulation using a moderate complexity BGC model (35 constituents) and an increased grid resolution that allows the formation of turbulent mesoscale eddies (30 to 200 km in size) in the ocean. Comparing with low resolution runs will allow us to assess whether standard ESMs are biased in their representation of the carbon cycle due to parameterized effects of sub-grid scale physics.

Progress

The ESM we are using is the newly developed Energy Exascale Earth System Model (E3SM, formerly known as ACME). Over the course of the IC grant, we were able to complete 65 years of simulation (as was proposed), though unfortunately a significant bug was discovered that invalidated the first half, resulting in a need to re-run. While 30 years of simulated time isn't ideal, we are still able to start quantifying the effects of explicitly resolved eddies on the biological pump. We are also very grateful to the IC leadership for granting us another year to finish this simulation.

As demonstrated in our 2017 annual report, we see some of the qualitative features that we had hoped for when proposing this work, such as very different biogeochemical behavior inside of eddies compared to directly outside of them. For this final report, we would like to be a bit more quantitative in the analysis of the effects of eddies on the biological pump. In particular, there are vast regions in the ocean (subtropical gyres) where biological productivity is relatively weak due to the low concentration of necessary nutrients in surface waters. One characteristic of some types of eddies is their ability to upwell nutrients from below the surface to where phytoplankton can use them (known as 'eddy pumping'). This process is completely absent from low resolution models.

Figure 1 shows the phytoplankton productivity, which is essentially the rate at which carbon is converted into cellular material via photosynthesis, in the Sargasso Sea (the subtropical gyre of the North Atlantic Ocean) for both the eddying model and the non-eddying model. The rate of production is important because it is related to the amount of carbon which is exported to the deeper ocean where it can remain for decades to centuries. As noted above, there is a relative minimum in the Sargasso Sea (denoted by the ovals in figure 1), but the eddy pumping mechanism is supplying enough nutrients for the high resolution case to agree well with estimates derived from satellite observations, while the low resolution average production is only about 60% of the data value. Note that the very large bias to the north of the gyre in the low resolution case (*i.e.,* very low production at high latitudes) is due to an unrealistic lack of vertical convective mixing.

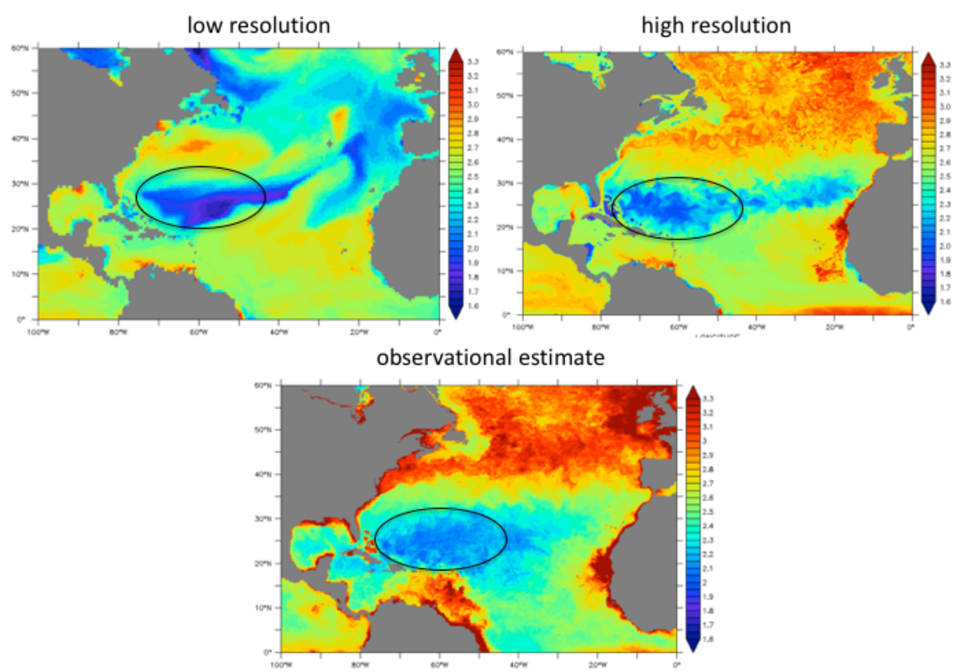

Figure 1. $\log_{10}$ of total production (mg-Carbon/m^2/day) due to photosynthetic phytoplankton for the month of June with current climate conditions. The ovals denote the general location of the Sargasso Sea. The average values for the Sargasso Sea are 83 mg-Carbon/m^2/day for low resolution, 139 mg-Carbon/m^2/day for high resolution, and 146 mg-Carbon/m^2/day for the observational estimate.

Once the simulation is finished, we will do a global analysis of the effects of eddies on the biological pump. This will include quantification of the relationship of photosynthetic production to the amount of carbon that is exported to the deep ocean, and the transport of carbon and nutrients via coherent eddies.

Financial Impacts

This simulation is being performed under the auspices of the DOE's Energy Exascale Earth System Model (E3SM) project, which provides 100% of Mathew Maltrud's salary, which has a $5.9 M/year LANL budget ($20 M over the entire DOE complex). Shanlin Wang is currently on leave at Xiamen University in China.